CHERRYWOOD
PLANNING SCHEME

Appendix E: Tufa Springs Mitigation Requirements

Annex A: ORIGINAL Appendix E

Annex B: JBA Catchment Study

1 Introduction

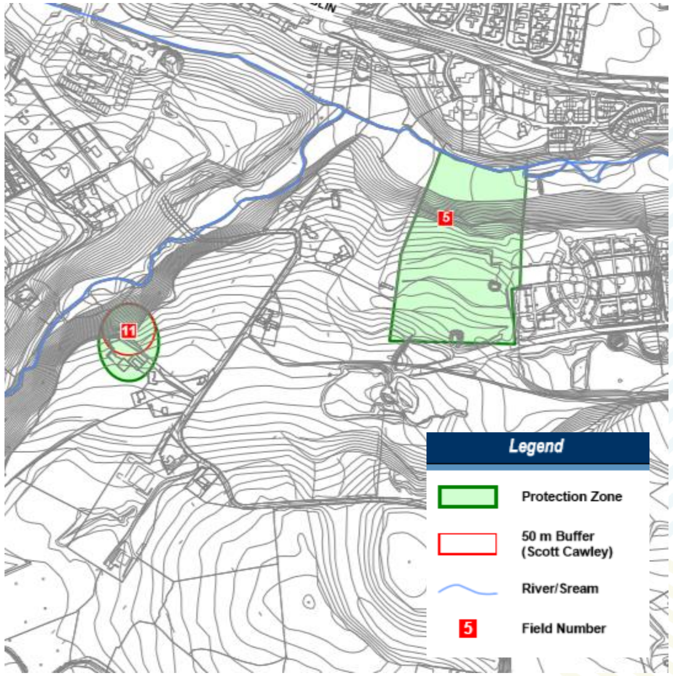
In September 2011, RPS produced a Phase 1 Hydrogeological Assessment of the Cherrywood Strategic Development Zone (SDZ) area (see Annex A-Original Appendix E) with a view to identifying potential sensitive tufa spring groundwater receptors that could be impacted by future development in the area.

The objectives of this study were to:

- Broaden the understanding of the tufa springs in the area;
- Highlight potential risks on the tufa springs;
- Recommend solutions and mitigation measures that may be needed to avoid negative impacts on the tufa springs.

This study identified two protection zone in which further assessment and mitigation measures would be required (see Figure 1-1).

Figure 1-1: RPS Protection Zones



Through an iterative site investigation and hydrogeological assessment processes, the understanding of mechanisms that support Tufa Spring No. 5 has increased and so the requirements of the Protection Zone associated Protection Zone require updating.

Please note the advice regarding the Protection Zone 11, remains as the original Appendix (see Annex A).

2 Current Understanding of the Hydrogeology of Tufa Spring 5

Since 2016, JBA Consulting have been commissioned by DLRCC to provide ongoing hydrogeological advice regarding the protection of the tufa spring. A range of further information has been made available to improve the understanding of the hydrogeological systems since 2011 including site investigations for particular developments within the Cherrywood Planning Scheme area.

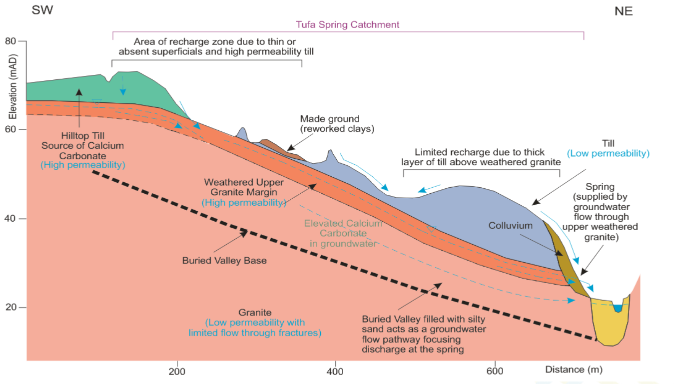
The current understanding of the hydrogeological system supporting Tufa Spring 5 is detailed in the JBA Catchment Study (see Annex B -JBA Catchment Study) and summarised in the Box below.

Box 1 - Tufa Spring Conceptualisation

The current hydrogeological conceptual model of the tufa spring has been developed from two reports previously produced by JBA Consulting and the additional site investigation data summarised in the section above. It has the following features:

- The tufa springs form and discharge where a buried valley filled with silty sand intersects with the valley side.
- The upper weathered margin of the granite bedrock which is observed in previous site investigations acts as a relatively high permeability layer which discharges groundwater to the buried valley from the surrounding area.
- The recharge is likely to be derived from an area of thinner/absent till which overlies the bedrock and higher permeability till deposits in the upper catchment. These high permeability tills are also likely to also be a key source of calcium carbonate for the spring.
- Recharge in the area immediately uphill of the spring is limited by a thick layer of low permeability till.

The updated conceptual site model is shown in figure below.



3 Potential Impacts and Catchment Sensitivity Zone

The JBA Catchment Study has divided the catchment into zones (see **Figure 3-1** below). These are based on the underlying geology and how the spring is supported by these areas.

For each Zone, there are two Potential Impact Classes described in **Table 3-1**.

<u>Any proposed development should not significantly change the nature or area of the catchment of the spring, through divergence of surface or groundwater away from the catchment</u>.

To note, Tufa Spring No. 5 is a mature developed tufa formation which is a priority EU Annex Habitat which is considered important at county level.

Table 3-1:Potential Impact Classes

Potential Impact Classes	Possible Mechanism	Spatial Locations Where Impact is Most Likely to Occur
Alteration of Recharge Characteristics	Reducing the permeability of the ground and infiltration of surface water through construction of extensive areas of hardstanding. Installation of drainage systems which change the spring catchment or lead to reduced recharge within the catchment.	Where groundwater recharge rates are likely to be higher, i.e. areas where till is relatively thin (or absent), or of relatively high permeability.
Alteration of Groundwater Flow Paths	Physical barriers to groundwater flow (secant piled walls, deep foundations for undercroft parking etc.) could be built through the upper weathered margin or buried valley. Deep permanent excavation below the local water table, or installation of deep service conduits.	In the lower part of the spring catchment, where till is thick, this impact mechanism is only likely to only occur with deeper excavations. Where till is thin or absent or higher permeability development works could have the potential to alter flow paths. It has been assumed that groundwater flow paths in the lower catchment will not be significantly affected by excavations and physical barriers in the upper catchment, i.e. all except very large excavations in the upper catchment will not change the groundwater catchment of the spring

In addition to the impact mechanisms identified above, direct damage to the spring could occur with developments close to the spring.

Figure 3-1: Catchment Sensitivity Classification

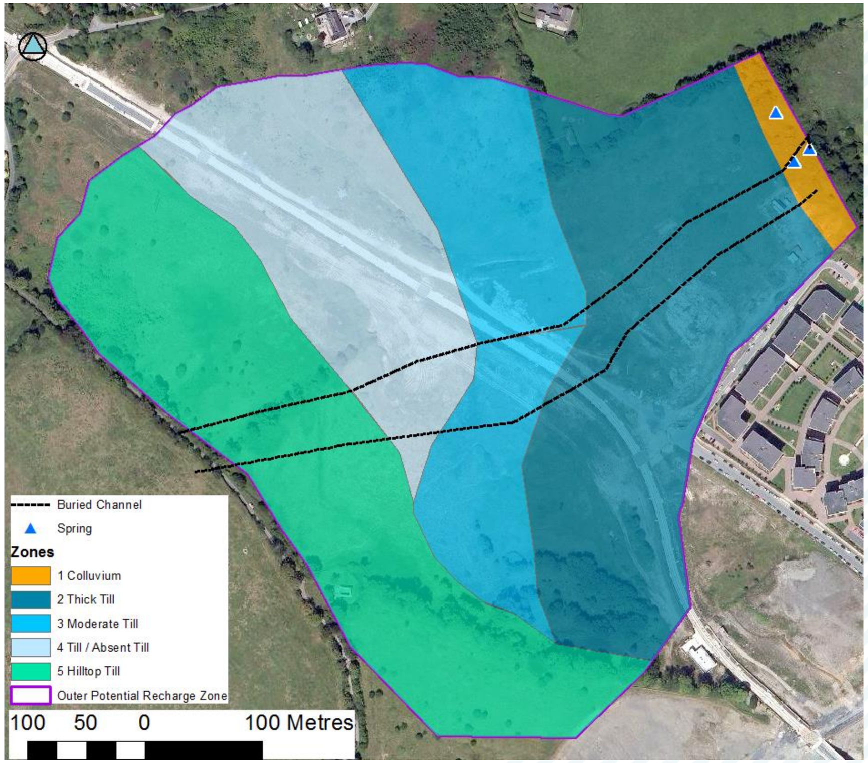


Table 3-2 provides a description of the potential development related impacts that could arise within each zone, and the outline recommended mitigation actions.

The last row of **Table 3-2** takes into account large scale development works such as extensive and deep excavations (more than 2.5m deep) which could fundamentally alter the groundwater system and therefore the future status of the springs.

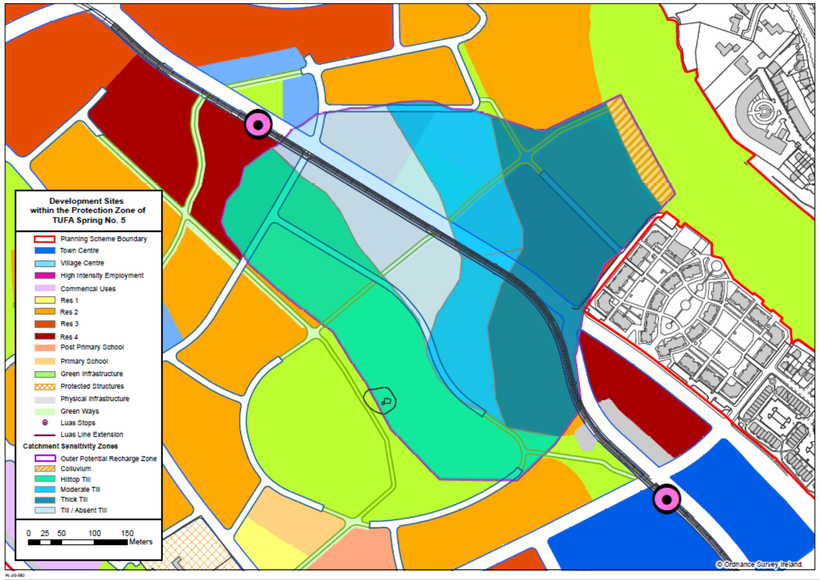
Such work**, anywhere within the Precautionary Spring Catchment** as defined in **Figure 3-1**, should be supported by a hydrogeological risk assessment and an appropriate level of site investigation**.**

In certain zones, excavations less than 2.5m could be undertaken without further excavations, as they would occur entirely in low permeability till deposits.

Through an iterative site investigation and hydrogeological assessment processes, the understanding of mechanisms that support Tufa Spring No. 5 has increased and so the requirements of the Protection Zone associated Protection Zone require updating.

Please note the advice regarding the Protection Zone 11, remains as the original Appendix (see Annex A).

Figure 3-2: Catchment Sensitivity Classification Overlaid with Map 2.2: Scale of Density taken from the Planning Scheme.



4 Analysis Requirements

While **Table 3-2** above outlines what type of impact mechanism could occur in each zone and where further analysis is required, this section provides an initial framework which may lead to the requirement of further analysis to be carried out on site by the applicant.

Guidance on this process is outlined under Table 4-1 below. These assessments shall be carried out <u>prior to the design of the layout of the proposed design on site and prior to any pre-planning workshops been carried out with the DAPT or the Planning Authority</u>.

The process is an iterative one and should not be deemed to be complete until the Hydrogeological Analysis carried out by the applicant indicates that their proposed development:

- will not significantly impact on the Tufa Springs, noting that Tufa Spring No. 5 is a mature developed tufa formation which is a priority EU Annex Habitat which is considered important at county level and has been given a High Rating under the Draft National Level Assessment been carried out by NPWS (2020, in draft).
- and that sufficient evidence has been provided to inform the Ecological Impact Assessment accompanying any proposed development/planning application on the development sites within the protection zone shown in Figure 3-1, that the proposal will not cause significant impacts on the Tufa Spring.

Prior to the lodgement of a planning application on any of the sites within the protection zone of the Tufa Spring as identified on Figure 3-1, the applicant will need to demonstrate that they have carried out the following:

- Engaged and suitably qualified Hydrogeologist.
- Prepared an Ecological Impact Assessment prepared by the Applicant supported by a Hydrogeological Analysis carried out by a suitably qualified Hydrogeologist in consultation with a suitably qualified Tufa Spring Ecologist.
- Must ensure that the proposed development will pose no significant impact on the Tufa Springs.

All works within the catchment will require assessment. The scale of the work required to prove no significant effects on the tufa spring will be dependent on a number of factors:

- The scale and nature of the works.
- The location within the catchment and the role that location plays in supporting the spring.
- The rounds of iterative investigations required to provide a robust hydrogeological baseline understanding of the area.
- The scale and nature of the measures required to mitigate impacts.

Small works, such as the installation of paths on the existing ground surface, which shed runoff to the surrounding ground may only require a screening assessment.

Larger scale works such as sub terrain carparks which partly lie beneath the water table may need to be supported by a Hydrogeological Risk Assessment support by a groundwater model which has been developed by several rounds of Site Investigation.

Table 4-1 below provides a framework of the stages potentially required. The conclusions of the assessment process carried out by the applicant/developer will need to be presented to and agreed with DLRCC. It is recommended that this is done as part of the pre-application consultation process and the design of the development should be based on the results of these assessments. This will aid the process when a development on site is lodged as a formal planning application.

Table 4-1 – Framework of Studies Required

Stage	**Activity**	**Consider if Enough Information has been gathered**
1	**Screening assessment** Are there activities that might affect the tufa springs through changes in recharge or groundwater flow pattern?	If there is no potential source of impact no further assessment required <u>If potential impacts continue to stage 2</u>
2	Develop initial hydrogeological conceptual model based on available data	
3	Review nature of the development	
4	Review mitigation measures available Outline Hydrogeological Impact assessment	If no feasible impact linkage identified, no further assessment is required (only valid if conservative assumptions are made) <u>If potential impacts are possible continue to stage 5</u>
5	Design and conduct site investigation to improve conceptual model Depending on the mitigation measures require this may include ongoing monitoring to capture the range of groundwater conditions the site experiences, or quantitative (e.g. modelling) assessments.	
6	Develop the conceptual model, mitigation measures and risk assessment further Support the risk assessment with quantitative assessment if appropriate	If impact linkages can be demonstrated to lead to no significant impacts, no further assessment is required. If this is not possible repeat Stages 5 and 6 until no significant impacts can be demonstrated

The Environment Agency (2007), Hydrogeological impact appraisal for dewatering abstractions, although developed for and specifically for dewatering activities, provides further useful guidance on the iterative process which should underlie the assessment process and the tiers of evidence that can support a hydrogeological risk assessment.

https://www.gov.uk/government/publications/hydrogeological-impact-appraisal-for-dewatering-abstractions

4.1 Screening

All proposals within the catchment should be screened by the applicant to assess

- whether they include activities which could cause the impact mechanism detailed in **Table 3-1**.
- Assess whether those activities are appropriate to the zone.

If at the screening stage activities are identified that could potentially impact the spring, further assessment will be required as outlined in Table 4-1.

4.2 Further Assessment

If potential impacts are identified, developments will only be permitted where it can be demonstrated by the applicant that these can be successfully mitigated against.

This should be presented in the form of a hydrogeological risk assessment which can form the basis of the technical information to inform the Ecological Impact Assessment of the scheme.

The information contained within the hydrogeological risk assessment should reflect the sensitivity of the location and the scale of the works being undertaken, and the significance of the impact mechanism that may be affected. Depending on the initial finding of the hydrogeological risk assessment and design constraints, the process may be iterative, and may require a number of rounds of investigation.

Where the Hydrogeological Risk Assessment concludes that impact mechanisms can be eliminated through the design of the scheme[1], mitigation measures developed will need to be supported by additional quantitative assessments which show that the functions of the existing hydrogeological system will be replicated.

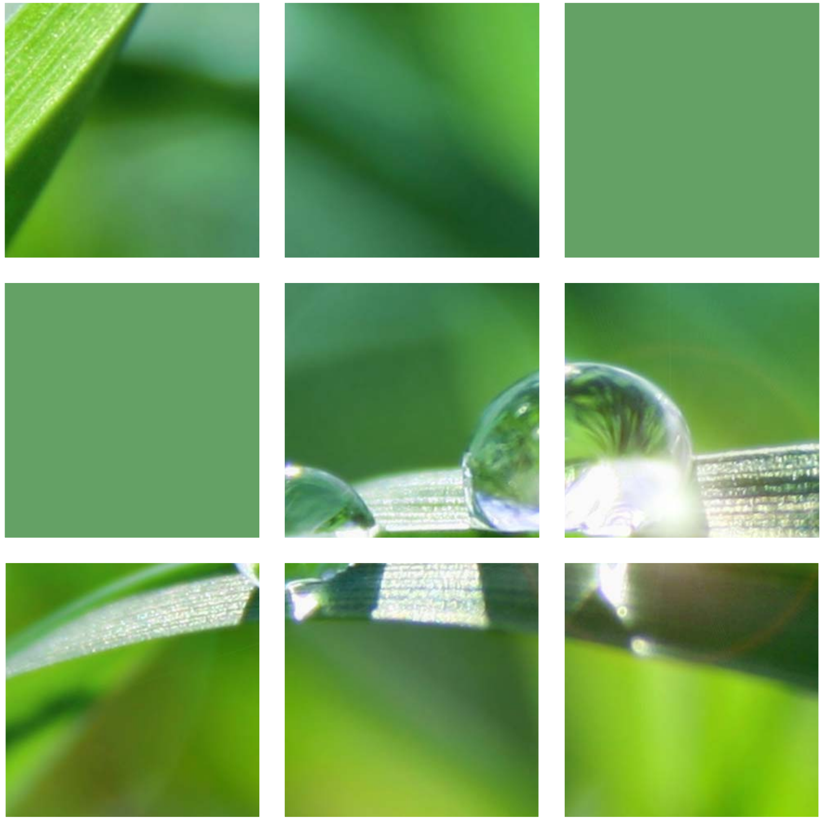
[1] Example of elimination - the depth of excavations are reduced to no change groundwater flood patterns

Annex A -Original Appendix E

RPS

Cherrywood Hydrogeology

Phase I Hydrogeology Assessment of the Cherrywood SDZ



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1 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

RPS were requested by Dún Laoghaire Rathdown County Council to conduct a Phase 1 Hydrogeological Assessment of the Cherrywood Strategic Development Zone (SDZ) area with a view to identifying potential sensitive groundwater receptors that could be impacted by future development in the area. As part of the ecological studies undertaken for the Cherrywood SDZ area, a number of tuffa spring formations have been identified.

The objectives of this study were to:

- Broaden the understanding of the tuffa springs in the area;
- Highlight potential risks on the tuffa springs; and
- Recommend solutions and mitigation measures that may be needed to avoid negative impacts on the tuffa springs.

1.2 TUFFA FORMATION & PROJECT APPRECIATION

Tuffa is a deposit of calcium carbonate that has deposited at the source of a spring emergence. Groundwater percolating through the soil and aquifer material can dissolve calcium from the parent material and precipitate calcium carbonate where groundwater emerges at the spring source. The chemical reactions are similar to those that cause the formation of stalagmites and stalactites in cave systems.

The significance of tuffa springs formation in relation to the Strategic Development Zone (SDZ) for Cherrywood is that where such springs occur, land development within the catchment area that feeds the tuffa spring can potentially impact these springs. The existing baseline conditions (tuffa spring) are being supported by an existing hydrological cycle whereby rainfall infiltrates the subsoil and discharges at spring emergences. When land developments block or reduce the amount of rainfall that can infiltrate the groundwater system, there can be a direct impact on the amount of groundwater recharge and an indirect down gradient impact on the tuffa springs.

2 METHODOLOGY

In order to provide a preliminary assessment of the tuffa springs and the potential impact of the planned development in the area, RPS conducted a Phase 1 Hydrogeological Assessment of the Cherrywood SDZ using the following methodology:

- Review of the Geological Survey of Ireland (GSI) bedrock, quaternary and groundwater information available;
- Desk top review of soil, geology and water sections of relevant Environmental Impact Statement (EIS) for the area (e.g. LUAS, M50 Scheme);
- Review of relevant and available geotechnical investigations conducted in the area; and
- Preliminary site walkover with the ecology team that had identified the location of the tuffa springs.

3 REVIEW OF EXISTING INFORMATION

3.1 HISTORICAL GEOLOGICAL MAPPING

The Geological Survey of Ireland's (GSI) historical field sheets for the area identify the study area as Limestone Drift with Granite bedrock exposure and drift around Carrickmines and Brennanstown House.

3.2 QUATERNARY & BEDROCK MAPPING

The GSI have identified the bedrock (**Figure 1**) underlying the site as comprising of Granite with a gradation between pale grey fine to coarse grained granite (Stratigraphic code Nt2e) in the west, to Granite with microcline phenocrysts (Stratigraphic code Nt2p) in the east. The bedrock is classified by the GSI to be a Poor Aquifer bedrock (Pl), which is generally unproductive, except for local zones.

The GSI's subsoil Quaternary mapping for the area indicates that Granite Till (TGr) underlies the majority of the study area in the central part of the site with localised areas of bedrock outcrop (Rck) along the M50 and to the west of the M50 (**Figure 2**). Limestone Till (TLs) is mapped in the eastern part of the study area that coincides with the observed locations of tuffa springs (refer to **Section 4.2**) with Alluvium around the Loughlinstown River.

3.3 RELEVANT EIA IN THE STUDY AREA

The LUAS Line B1 Sandyford Industrial Estate to Cherrywood EIS, specifically Area 5 Volume 2 Ballyogan Wood to Bride's Glen, crosses through the study area. The soil and water sections of this EIS refer to a generally low permeability subsoil (descried as glacial till) overlying weathered granite bedrock. The weathered granite bedrock was noted to provide private groundwater abstractions at the time in the Laughanstown area that were due to be replaced by public mains water.

4 WALKOVER OBSERVATIONS

4.1 GENERAL OBSERVATIONS

A site walkover survey was completed on 9 June 2011 in the accompaniment of Mr Paul Scott of Scott Cawley. Weather conditions on the day were dry with sunshine and there was antecedent rainfall on the two days prior to the walkover (3.1mm and 2.7mm recorded at Dublin Airport).

Soil and rock outcrop were observed at several locations during the walkover. Subsoils in the centre of the study area were well exposed from the earth works that have been completed and significant calcareous carbonate source material was evident in the abundant limestone gravel and cobbles observed, which would provide source material to support tuffa spring formation. Granite bedrock was observed at several locations along the river valley running east west to the south of Brennanstown road and granite shallow subsoils were also observed along these locations. Granite parent material in the soil will not provide source material to support tuffa spring formation.

Figure 3 illustrates the locations of the observations made during the site walkover and **Table 1** provides a description of observations made during the walkover.

4.2 TUFFA SPRINGS

Tuffa spring formations were observed at several locations across the study area and can be subdivided into the following broad categories:

Immature recently formed tuffa as the result of recent earthworks exposing shallow perched groundwater tables and spring/seepage along new embankments. Several examples were evident along the northeast - southwest trending embankment to the northwest of the Wyatville Link Road (location 1 on **Figure 3**). Photographs 1 and 2 (**Appendix A**) illustrate this in close up and from a distance.

Mature, high quality tuffa springs with active groundwater flow and calcareous carbonate precipitation with associated plant communities. Two large examples were present on the southwestern flank of the river valley to the southwest of the N11 (location 5 on **Figure 3**) and illustrated in Photographs 3 and 4 (**Appendix A**).

Lower quality tuffa spring formations were located along small drainage channels (with the associated plant communities less dominant). An example occurs at spring seepage to the south of Brennanstown Road on the southern slope of the river valley (location 11 on **Figure 3**) and illustrated in Photograph 5 (**Appendix A**). A rare species of mollusc was also identified by Scott Cawley at location 11.

A complete description of notable field observations is contained in **Table 1** with locations illustrated in **Figure 3**. In summary, a small number of localised high quality tuffa spring formations were observed on the southwestern flank of the river valley to the southwest of the N11 (location 5 on **Figure 3**). The spring flows observed to be feeding one of these deposits was located approximately 1/4 way down the slope embankment, indicating a relatively shallow perched groundwater discharge at this location.

Tuffa spring formations were not widespread across the remainder of the SDZ, with localised recent immature examples present along recently excavated areas (location 1) and lower quality formations at one location in the northwest of the study area (location 11).

The absence of extensive tuffa spring formations along the southwest side of the river valley indicates that the groundwater flow systems supporting these formations are relatively limited in aerial extent. Photograph 6 (Appendix A) illustrates the nature of a well drained slope without any spring emergence 100m to the northwest of the large tuffa springs observed at location 5.

The mature tuffa spring formations observed at location 5 (**Figure 3**) are the only maturely developed tuffa formations within the limits of the SDZ. RPS also understands from Scott Cawley that the tuffa spring formations at location 5 correspond to an EC Habitats Directive Annex I habitat. These factors combined ensure that location 5 will be most important for the proposed SDZ in terms of the impacts of the development on the hydrogeology - ecology interaction of the area.

The more immature tuffa formations identified around the site are insufficiently developed at this time to be considered an issue of high hydrogeological protection, with the exception of location 11. Location 11 has been identified by Scott Cawley as an ecologically sensitive area within the SDZ and as such the hydrogeological impacts of the SDZ development on this site will also be important to consider.

Table 1. Field Observations

Map Location	Observation	Groundwater	Tuffa Spring Sensitivity/Priority Rating
1	Recently formed tuffa springs at base of excavations on the edge of cleared land. Position approximately 4m below natural ground level. Additional tuffa spring formations along sloped embankment created by excavations for development site approximately 2-3m below natural ground level	Seepage and standing water	Moderate
2	Ditch cutting with calcareous and granite source parent material in silty subsoil	Dry	Low
3	Limestone dominated subsoil exposed across development site with dark grey limestone gravel and cobbles within a silty subsoil matrix.	Dry	Low
4	Calcareous moss and orchids at the top of steep sloped bank.	Damp ground	Moderate
5	Large tuffa spring (approx. 15m wide x 2-3m length) with active spring flow and tuffa formation around vegetation. Second suspected tuffa formation heavily overgrown 50-100m north of first formation.	Spring emergence approximately ¼ way from the top of the slope. Saturated soils in the base of the slope.	High
6	Dry grass land slope	Dry	Low
7	Sandy subsoil visible along river floodplain. Adjacent slope embankments dry with no observable spring /seepage discharges	Dry	Low
8	Minor seepage at top of slope, possible marl formation	Seepage	Low
9	Steep embankment to river, dry, with weathered granite bedrock and shallow granite subsoil above bedrock.	Dry	Low
10	Slope with dry soil exposure, granite subsoil.	Dry	Low
11	Spring emergence amongst boulders at top of slope. Concrete water holding tank adjacent. Minor tuffa spring formation along runoff stream from spring 10-15m long by 2-3 m wide. Rare molluscs were identified by Scott Cawley.	Spring	Moderate - High
12	Well drained land, granite subsoil exposed in excavation.	Dry	Low
13	Dry slopes with granite weathered subsoil exposed along base adjacent to river.	Dry	Low

5 PRELIMINARY CONCEPTUAL HYDROGEOLOGICAL MODEL

Based on the information reviewed and the site walkover conducted, the preliminary conceptual hydrogeological model for the site can be described as follows:

- Localised shallow groundwater flow is expected to be within the more permeable zones within the subsoil across the SDZ;
- The limestone parent material (e.g. gravel, cobbles and boulders) with the subsoil is the primary source material for the calcium carbonate to be dissolved by infiltrating rain water;
- Groundwater flow paths are expected to be relatively short (100's m in length) within the subsoil material as evidenced by the relatively high levels of discharge along the embankments of drainage channels and associated tuffa spring formations;
- Groundwater flow within the shallow granite bedrock is not considered to be a critical component supporting tuffa spring formations as groundwater will not be enriched with calcium bicarbonate from the granite rock; and
- Overall groundwater flow directions are expected to follow the local topography with the predominant regional flow direction to the east towards the river valley. Shallower local groundwater flow directions will mirror local variations in the topography and discharge to streams and shallow springs where the geological conditions are favourable (e.g. localised more permeable sand and gravel lenses and bodies within the overburden.

6 POTENTIAL IMPACTS AND MITIGATION

6.1 POTENTIAL IMPACTS FROM THE SDZ

The hydrogeology below the study area has been outlined in **Section 5** of this report. Under current conditions, effective rainfall recharges shallow groundwater in the subsoil and weathered bedrock below the study area. Groundwater within the study area flows towards sloped embankments, where it discharges as a spring or seepage, or to the rivers/streams where it discharges as baseflow. The development of the SDZ has the potential to alter the hydrogeology in several ways that are discussed below:

- The creation of artificial drainage below significant areas of the SDZ has the potential to divert rainwater from groundwater recharge to storm runoff, thereby reducing groundwater recharge. This would reduce the volume of groundwater discharging to the observed tuffa springs and river systems.
- Excavation of soils for landscaping purposes has the potential to reduce the nature of subsoil aquifers below the SDZ lands and create spring discharge of groundwater where excavations proceed below the shallow perched groundwater or the groundwater table.

6.2 MITIGATION MEASURES FOR SDZ DESIGN

Several mitigation measures should be considered during the design stage for sensitive areas within the SDZ in order to minimise the potential impacts to the tuffa springs.

1. A Sustainable Urban Drainage Systems (SUDS) design philosophy should be employed for the SDZ;
2. The construction of hard standing areas should be minimised in the catchments immediately up gradient of the high quality tuffa springs (e.g. location 5) in order to minimise the potential for disruption to recharge in these areas.;
3. Artificial recharge systems should be considered where possible in sensitive areas, specifically up gradient from high quality tuffa spring (e.g. location 5) discharges in order to maintain the overall hydrological balance if development cannot be avoided in these areas; and
4. Landscape proposals should be considered in relation to the position of the groundwater table below the site so as to avoid possible interference with natural groundwater flow directions to sensitive receptors such as the high quality tuffa springs (e.g. location 5).

7 CONCLUSIONS & RECOMMENDATIONS

7.1 CONCLUSIONS

In summary, localised areas of tuffa spring formation have been observed within the SDZ. These appear to be supported by relatively shallow groundwater flow systems within permeable zones of the subsoil. The limestone parent material within the subsoil is acting as the source of the calcium carbonate. Tuffa spring formation is limited to where this is present and where there is a groundwater flow and discharge such as at localised slope banks. As these are relatively high up the embankments it suggests the presence of shallow perched groundwater flow systems that are not laterally extensive. The catchment areas feeding these tuffa springs are sensitive to future land changes that create impermeable surfaces, which will reduce groundwater recharge and ultimately discharge to these localised tuffa springs.

The most significant of these tuffa spring formations has been located to the southwest of the N11 on the south-western flank of the river valley, (location 5 on **Figure 3**). A low quality tuffa spring formation which is ecologically significant was also observed high on the northwest sloping boundary of the SDZ. (location 11 on **Figure 3**). These two tuffa spring formations will be dealt with in the recommendations below.

7.2 RECOMMENDATIONS

A number of high level recommendations have been made in relation to potential mitigation principles for the SDZ design (e.g. avoidance of sensitive areas, use of SUDS systems and possible use of artificial recharge). In line with the avoidance principle two spereate protection zones have been developed to encompass the tuffa spring formations at location 5 and location 11 and the most likely catchment areas that feed the individual tuffa formations.

The protection zone (**Figure 4)** relevant to location 5 extends to the southwest and upgradient of the tuffa formation to where the land rises again out of a topographical dip approximately 25m/30m in that southwesterly direction. To the northwest the protection zone extends to the boundary line of neighbouring agricultural land where a drainage ditch has been dug. The southeast boundary of the protection zone is the previously developed land. The proposed protection zone covers an area of 380m by 230m. With further field investigations the protection zone may be refined and more accurately delineated.

The protection zone (**Figure 4**) relevant to location 11 coincides largely with the 50m buffer zone recommended by Scott Cawley. The protection zone has been extended 50m past the recommended buffer zone to the west of the tuffa spring formation, giving a 100m protection zone in this direction to allow for a conservative estimate in the length of the flow path to the tuffa spring. Topographic contours suggest that flows from the east are unlikely to be contributing to the tuffa spring at location 11.

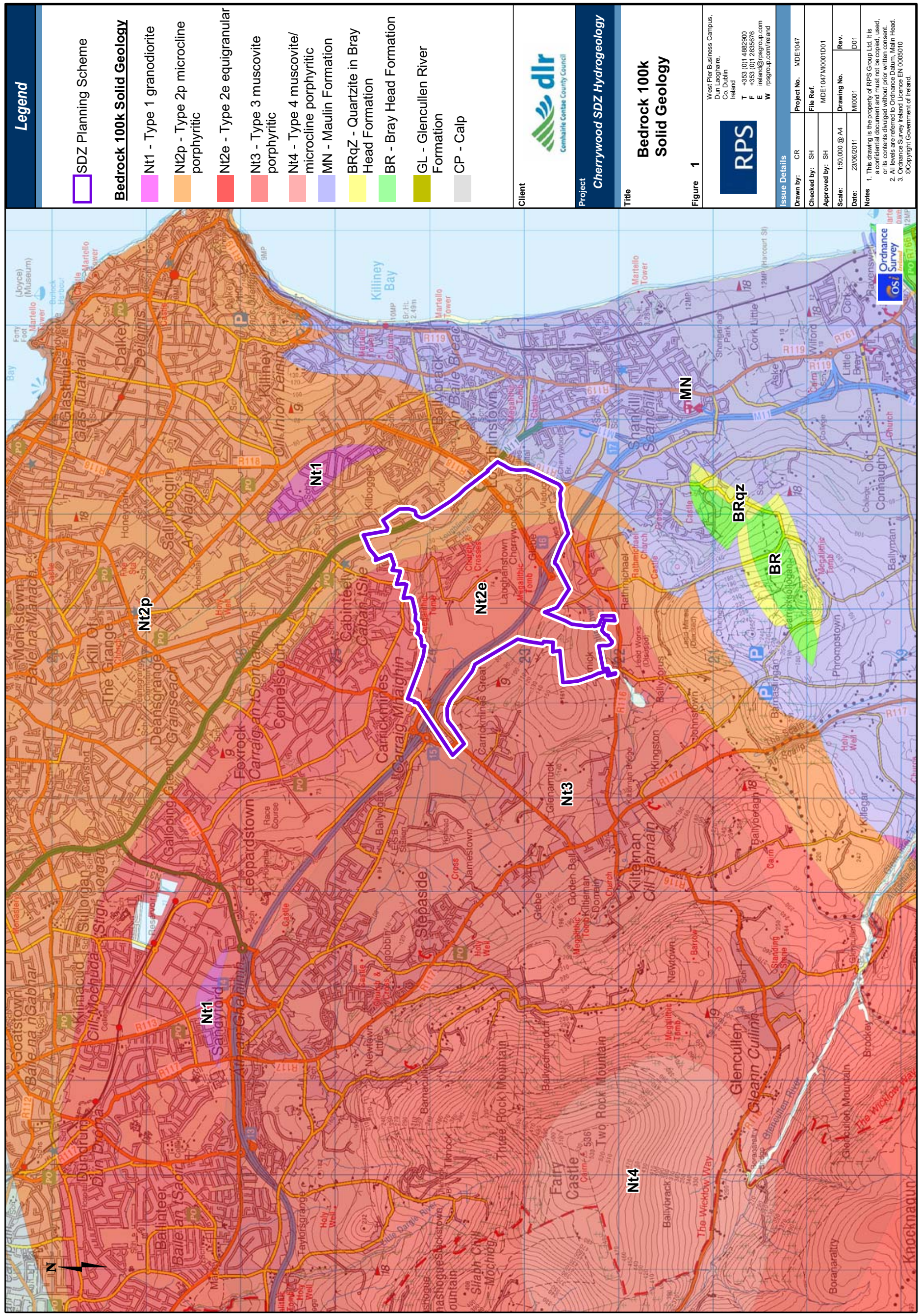
If avoidance of the sensitive catchment at location 5 is not possible, a targeted hydrogeological site investigation is recommended so that the hydrogeological system can be more completely evaluated and a baseline monitoring programme can be established on which to predict potential development impacts more completely. A targeted hydrogeological investigation would also help to refine the extent of the protection zone. Ideally this should include:

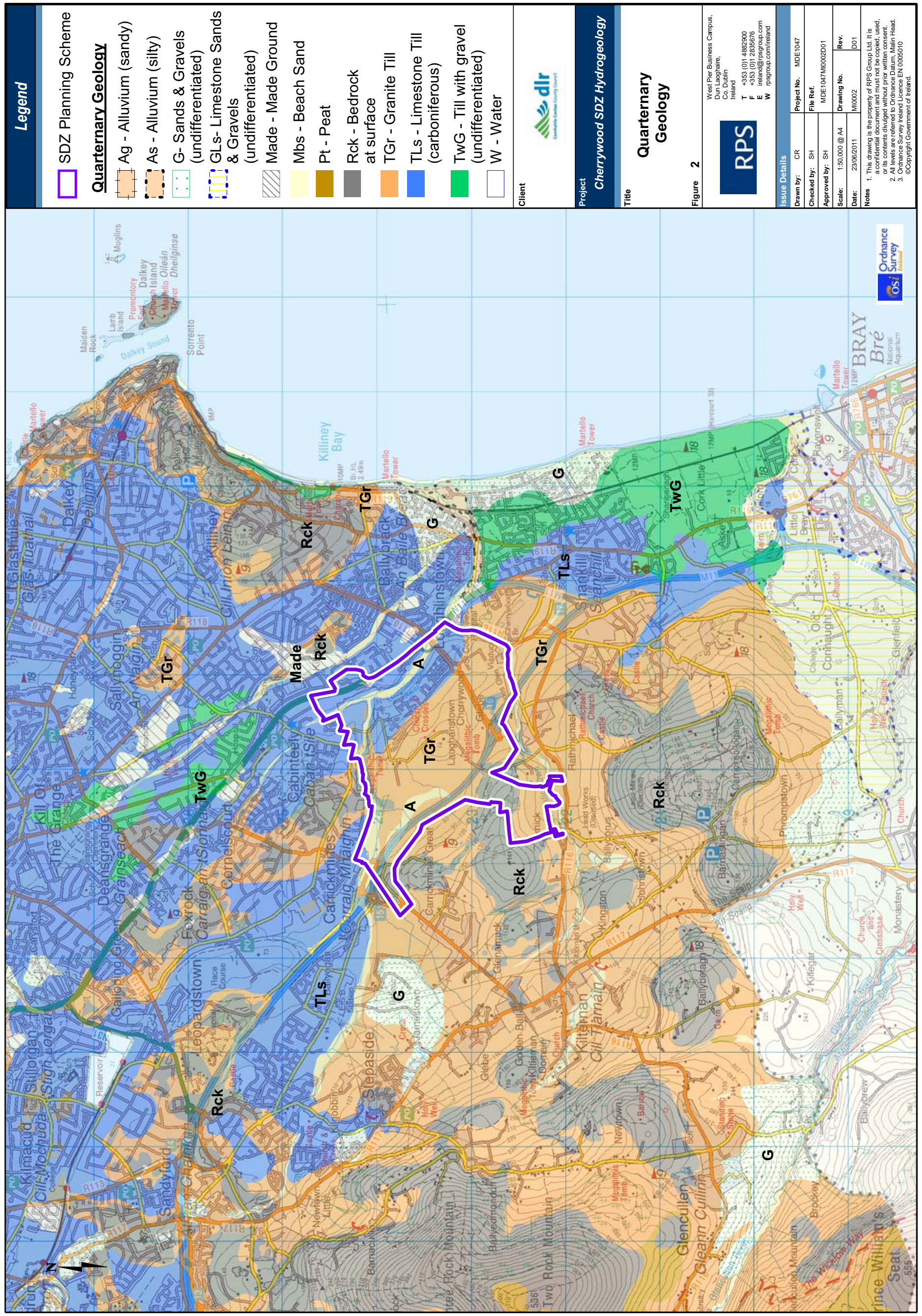
- Trial pit excavation to a nominal depth of 2.5m – 3m at approximately 15 locations across the designated protection area to more accurately assess subsoil geology in the catchment.
- Installation of a groundwater monitoring borehole network upslope of the spring emergence. 4 wells minimum, 6/7m deep or to a depth of 3m below the water table, located directly above and to either side of the spring emergence using a shell and auger drilling rig.

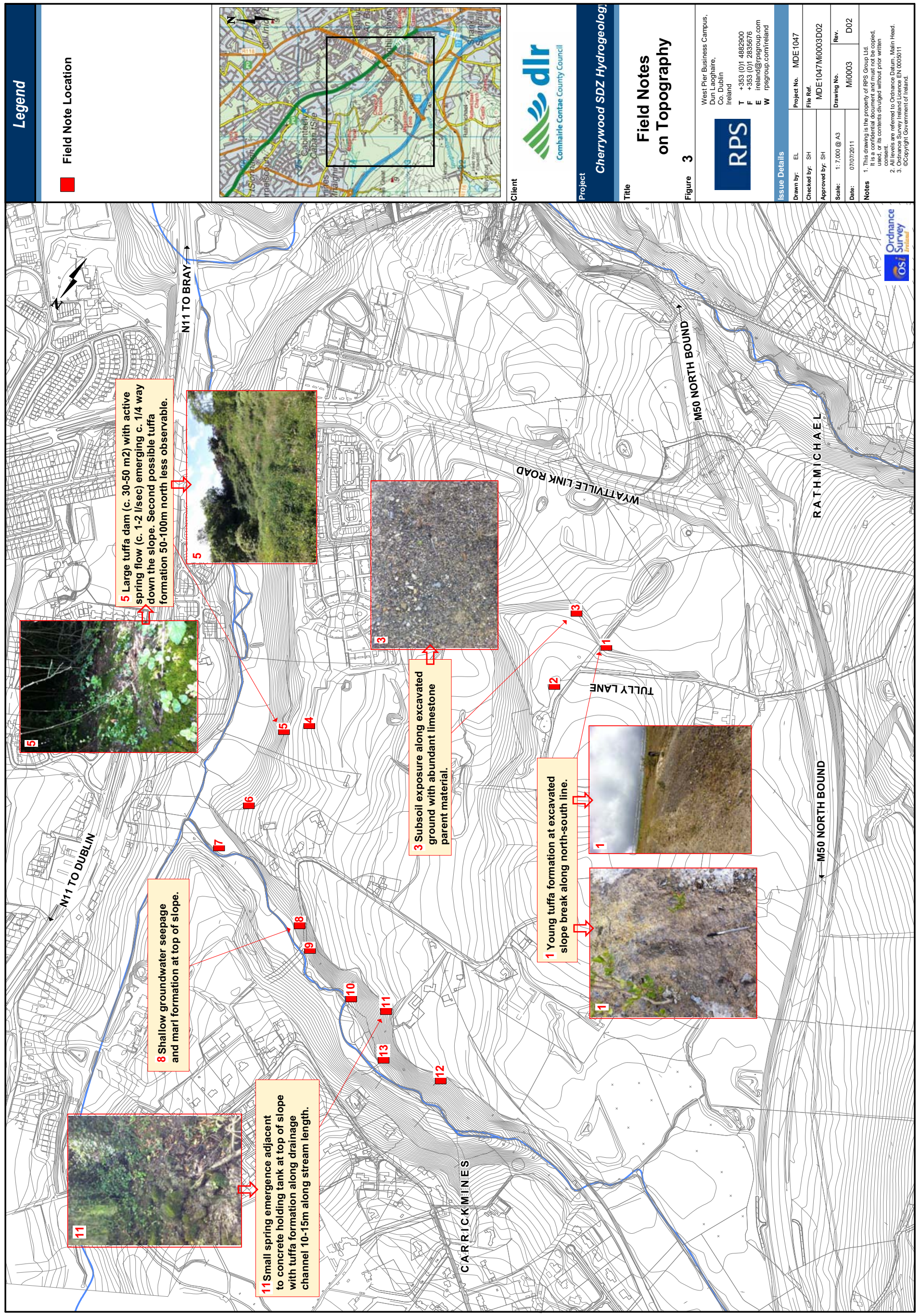
- Groundwater levels to be monitored in all boreholes over 12 month period using data loggers.
- Groundwater quality to be assessed in boreholes closest to the tuffa formation and at the spring emergence, (bi-monthly). Samples to be tested for major ions. – Ca, Na, CO_3, Cl, Mg, N
- Calculation of the mass water balance for the sensitive catchments above the tuffa springs to assess the overall impacts from future land use development changes in the catchment area.

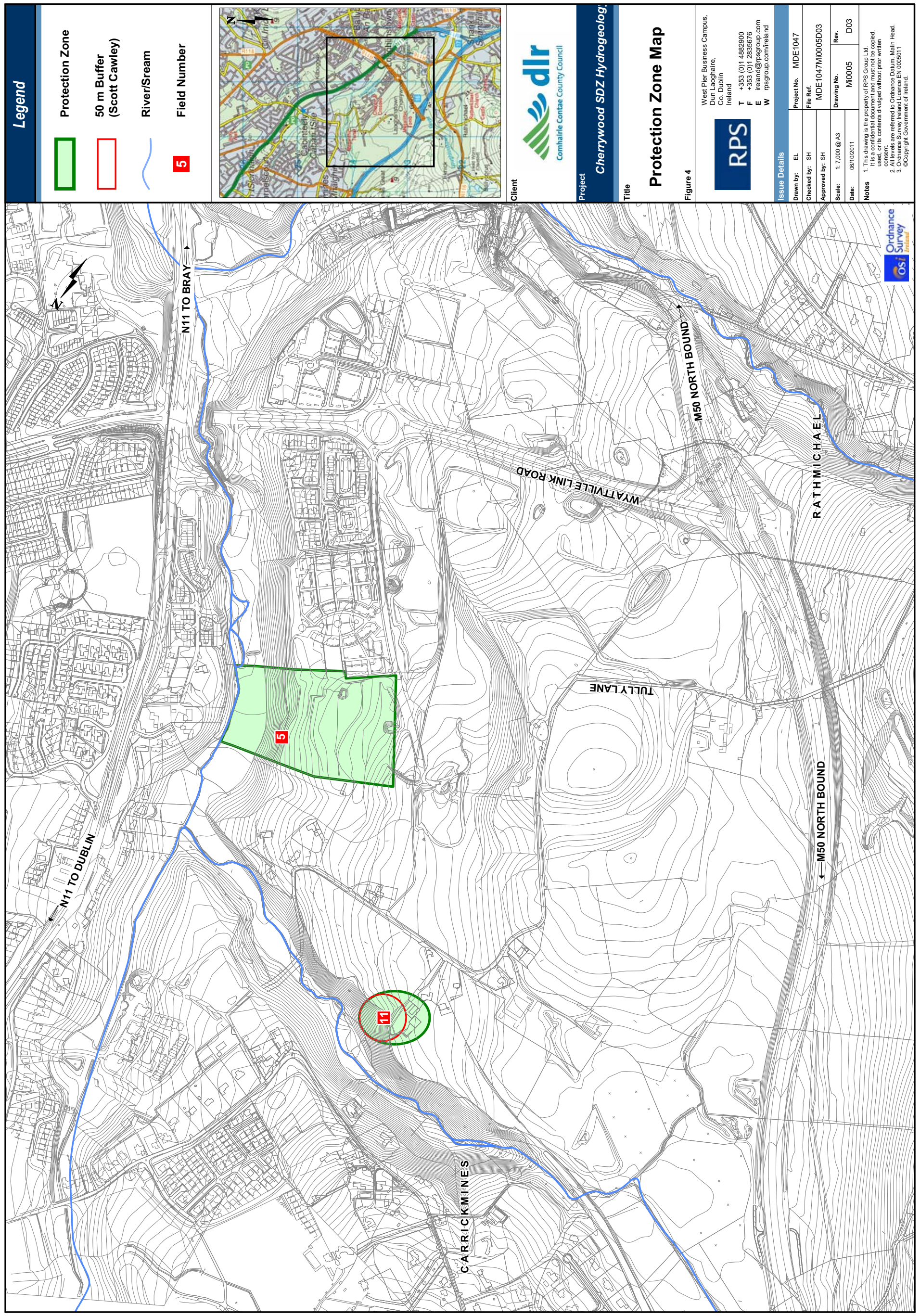
APPENDIX A

PROJECT FIGURES




Legend
SDZ Planning Scheme
Quarternary Geology
Ag - Alluvium (sandy)
As - Alluvium (silty)
G- Sands & Gravels (undifferentiated)
GLs- Limestone Sands & Gravels (undifferentiated)
Made - Made Ground
Mbs - Beach Sand
Pt - Peat
Rck - Bedrock at surface
TGr - Granite Till
TLs - Limestone Till (carboniferous)
TwG - Till with gravel (undifferentiated)
W - Water
Client
dlr
Project
Cherrywood SDZ Hydrogeology
Title
Quarternary Geology
Figure 2
RPS


Legend
Field Note Location
Client
dlr
Project
Cherrywood SDZ Hydrogeology
Title
Field Notes on Topography
Figure 3
RPS
N11 TO BRAY
N11 TO DUBLIN
WYATTVILLE LINK ROAD
TULLY LANE
M50 NORTH BOUND
RATHMICHAEL
CARRICKMINES
5 Large tuffa dam (c. 30-50 m2) with active spring flow (c. 1-2 l/sec) emerging c. 1/4 way down the slope. Second possible tuffa formation 50-100m north less observable.
3 Subsoil exposure along excavated ground with abundant limestone parent material.
1 Young tuffa formation at excavated slope break along north-south line.
8 Shallow groundwater seepage and marl formation at top of slope.
11 Small spring emergence adjacent to concrete holding tank at top of slope with tufa formation along drainage channel 10-15m along stream length.



APPENDIX B

PROJECT PHOTOGRAPHS

Photograph 1 – Close up view of new tuffa formation observed along slope break (ref Location 1 on Figure 3).

Photograph 2 – View of new tuffa formation (where person is standing) observed from a distance along slope break (ref Location 1 on Figure 3).

Photograph 3 – Close up of tuffa (orange material surrounded by moss) and spring located along southwest bank of valley at location 5 (refer to Figure 3).

Photograph 4 – Distant view of tuffa spring (heavily overgrown area to the left of trees) located along southwest bank of valley at location 5 (refer to Figure 3).

Photograph 5 –Tuffa formation along drainage stream from spring emergence at location 11. Concrete water holding tank visible at top left corner of image.

Photograph 6 – Dry well drained land without spring or tuffa emergence along western bank of River valley, refer to location 6 on Figure 3.

Annex B - JBA Catchment Study Tufa Spring No. 5

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1 Introduction

This interim note summarises the updated assessment of a catchment study to spatially assess areas that may be important in supporting a sensitive groundwater fed tufa spring bounding the Cherrywood Strategic Development Zone. An initial catchment study was presented in 2018 on behalf of the County Council. This update is based on additional intrusive site investigations carried out by developers and by JBA in the catchment.

This note summarises provides an update of our understanding of the functioning of the spring, which was presented in three previous reports prepared by JBA Consulting. It has the following structure:

- Presentation of most recent additional site investigation data (completed in early Spring 2019) involving excavation of trial pits and advancing groundwater monitoring boreholes,
- An update of the existing hydrogeological Conceptual Model of the Tufa Spring,
- Identification of potential impact mechanisms that could affect the future integrity of the tufa spring,
- Further baseline assessment of the catchment supporting the tufa spring,
- Spatial zoning of the catchment to identify:
  - The hydrogeological role of catchment zones in supporting the spring,
  - Potential impact mechanisms that might affect the spring in each zone,
  - The broad nature of mitigation measures required in each zone.

2 Data Sets

The following datasets were available for review for this report.

Table 2-1: Data Sources

Area	Source
Topo-graphy	LIDAR
Historic Maps	25 inch 1888-1913 6 inch 1837- 1842 Available at http://map.geohive.ie/mapviewer.html
Site Investigation	GSI National Geotechnical Borehole Database – Report Numbers 1461, 2589, and 6043 Available at http://dcenr.maps.arcgis.com/apps/MapSeries/index.html?appid=a30af518e87a4c0ab2fbde2aaac3c228 Site Investigation Ltd – 2001 – Four Borehole logs covering development to the south. Ground Investigation Ireland Ltd – 2017 – 9 boreholes, 14 Trial Pits on land immediately uphill of Tufa Spring. Ground Investigation Ireland Ltd – 2017 – Site at Domville, Cherrywood, Dublin 18 – Site Investigation Report. JBA Trial Pitting 2018– See Appendix A. Causeway Geotech, April 2019, Cherrywood Ground Investigation – See Appendix B.
Aerial Photograp	Geohive 2000, 2005 and Latest Aerial Photographs available at http://map.geohive.ie/mapviewer.html

hy	Google Earth
Reports	Stephen Buss Environmental Consulting, September 2016, Hydrological Monitoring of Tufa Spring at Cherrywood. RPS, September 2011, Phase 1 Hydrogeological Assessment of the Cherrywood SDZ. Engineering Planning Report for a Proposed Residential Development at Domville, Cherrywood, Dublin 18 for William Neville & Sons – Muir Associates Ltd. JBA Consulting, July 2018, Review of Response to CFI (Planning Reference DZ17A/0714)
Thesis	MD Lyons (2015), The Flora and Conservation Status of Petrifying Springs in Ireland.

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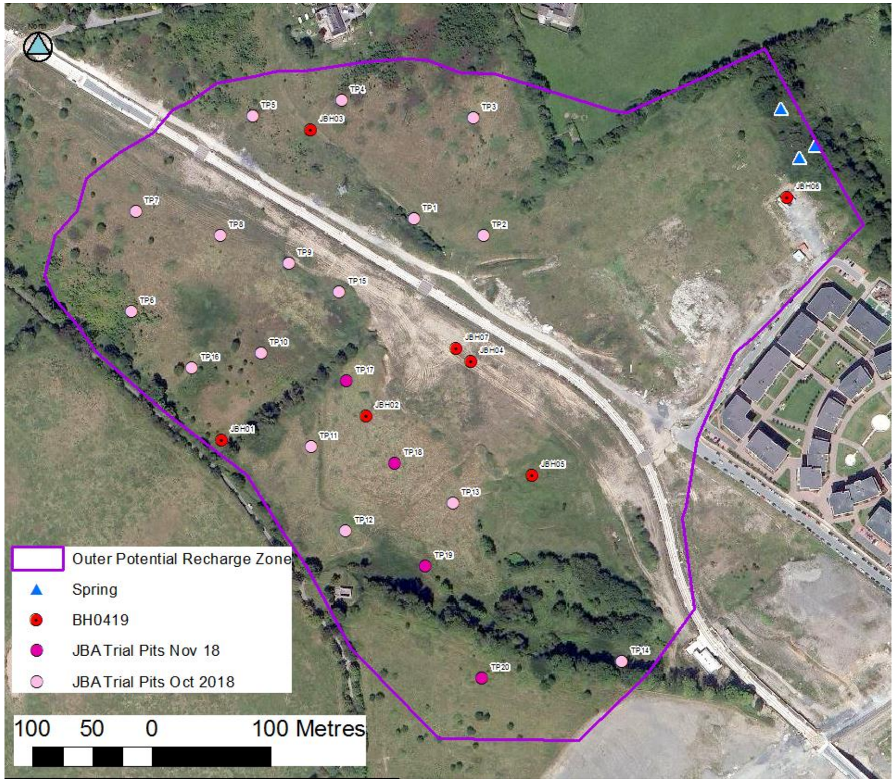
3 New Intrusive Site Investigation Information

Additional site investigations has been conducted in 2019 under the supervision of JBA to provide additional characterisation of ground and groundwater conditions within the spring catchment (See Trial Pit logs in Appendix A and Causeway Geotech 2019 in Appendix B). The locations of new investigation points are shown in the figure below and the supporting documents are provided in the appendices of this note.

Figure 3-1: Exploratory Locations



The site investigation identified three significant findings that have been used to update the conceptual model. These are discussed below.

3.1 Hilltop Till

Trial Pitting has identified a distinct type of deposit on the top of the hill, across the south and western area of the spring catchment (see Figure 3-3). The trial pits in this area identified a relatively thick sequence of superficial deposits which included deposits sands and gravels from 1 to 5m thick. These deposits are not seen elsewhere in the catchment and are likely to be a source of the carbonate and much of the recharge that the tufa is dependent upon. The nature of these deposits is collaborated by RPS 2011 observations (see Figure 3 3) which also identified limestone rich till and tufa formations on a cut slope on the same hill to the south east of the study area. Additional water chemistry data for groundwater found within these deposits is discussed in Section 3.3

Figure 3-2: Detail from RPS 2011

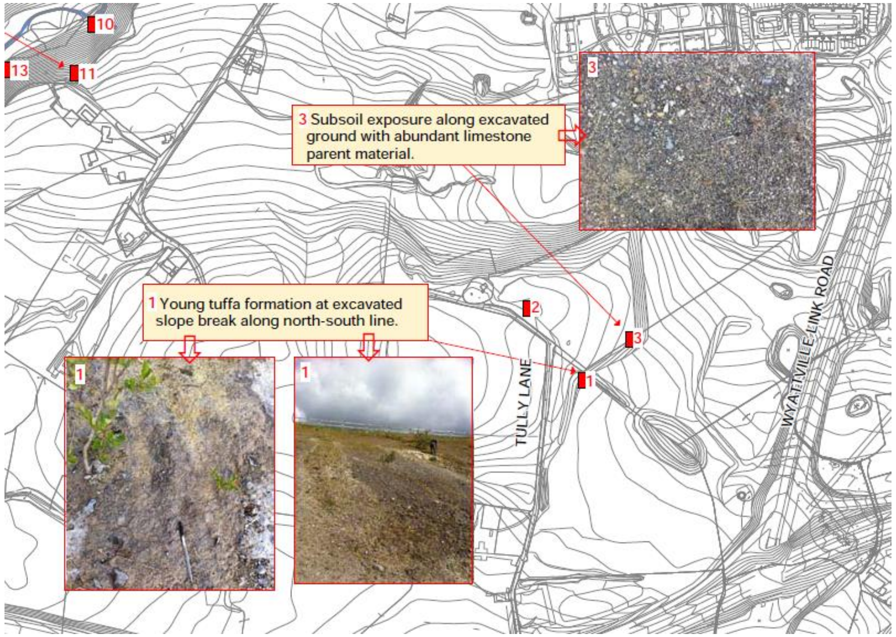


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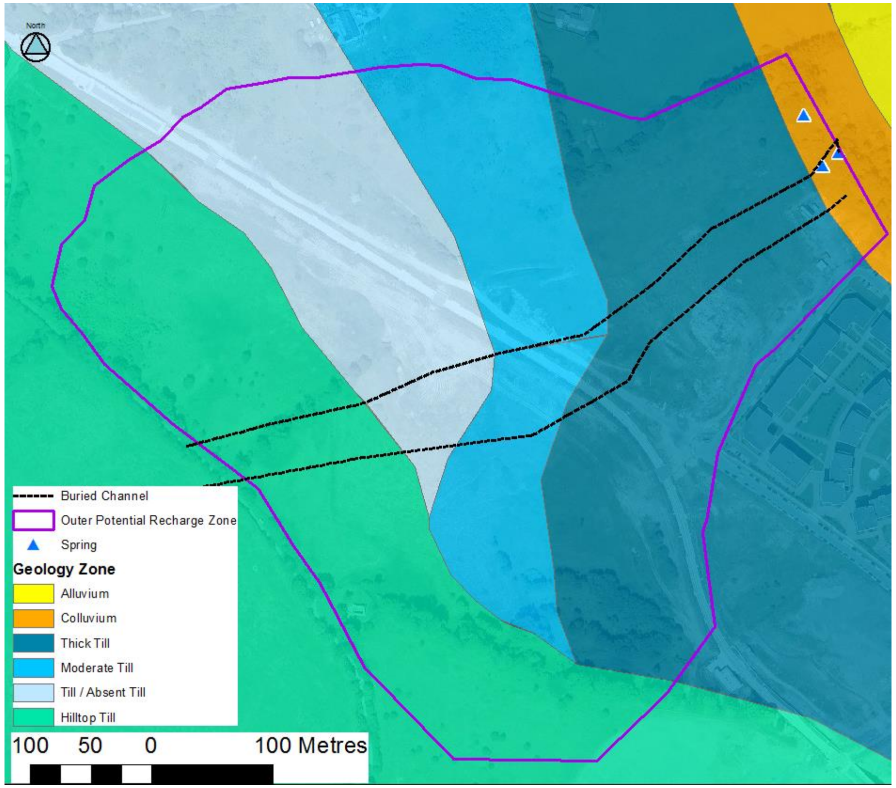
Figure 3-3: Broad Geological Classification Zones



3.2 Buried Valley

Four of the new boreholes identified a thick layer of greyish white silty sand at their base. Similar deposits at depth had not been identified in previous site investigations.

Table 3-1: Identified Buried Valley Deposits Summary

Borehole	Thickness of Silty Sand Deposits
JBH01	10m+
JBH02	6m+
JBH04	14m+
JBH06	10m+

Review of the surround site investigation information suggests that these deposits fill a steep sided buried valley cut into the granite bedrock surface. The approximate line of the buried valley is shown in Figure 3-3. For example, JBH07 and 04 are approximately 16 metres apart, bedrock at JBH07 is found at 3.2mbgl, whereas the base of JBH04 at 16mgl does not find the bedrock. This indicates the this buried valley has steep sides with at least a 1 in 1 slope. It may be a relatively narrow feature, which would explain why previous site investigations did not identify it.

Identifying the buried valley is important for updating our understanding of the location of the tufa spring. In effect, the buried valley may act as a conduit for groundwater flow focusing discharge at the spring. This may also explain why the neighbouring slopes have no groundwater discharge. However, there is a 200m gap between identify the buried valley deposits at JBH4 and at JBH6 (above the spring). Further site investigation would be recommended to try to identify the line of it through this area, possibly with the aid of non-intrusive investigation techniques such as geophysics.

3.3 Water Chemistry Results

Groundwater chemistry results suggest that that the soils found at hill top till act as a key source of calcium carbonate. Analysis indicates that, using field and laboratory measurements of pH, to calculate the Calcium Carbonate Saturation Index leads to varying results. Depending on the method of calculation, the results show groundwater lies at or close to supersaturated with respect to Calcium Carbonate in the majority of samples (see Table 3-2). This includes JBH01 showing Calcium Carbonate is present in the groundwater system in high concentrations from the top of the catchment.

Table 3-2: CaCO3 Saturation Index[1]

Sample ID		JBH - 1	JBH - 2	JBH - 3	JBH - 4	JBH - 5	JBH - 6	JBH - 7	Spring
17/04/2019	Field	0.37	0.17	0.12	0.11	0.51	0.48	0.43	N/A
	Lab	0.15	-0.48	-0.31	-0.31	0.13	0.08	-0.11	
14/04/2019	Field	0.12	-0.72	-0.53	-0.47	-0.26	-0.18	-0.53	-0.088
	Lab	0.14	0.08	-0.06	0.24	0.23	0.08	0.16	0.35

Table 3-3 presents water quality measurements at Cherrywood and the range of water quality results presented in Lyon (2015). Lyon (2015) sampled 115 tufa springs across Ireland and presents the mean, medium, minimum and maximum concentrations of a range of parameters. The table shows the parameters at Cherrywood are within the range of the Lyon samples, notably with generally high Calcium and Alkalinity

[1] The Saturation Index (SI) is a method of determining whether water will deposit calcium carbonate or maintain it in solution. Values greater than 0 are supersaturated.

levels and lower nitrate levels.

Table 3-3: Water Quality Parameters at Domville vs Parameters at other Tufa Springs (mg/l)

Sample ID	JBH - 1	JBH - 2	JBH - 3	JBH - 4	JBH - 5	JBH - 6	JBH - 7	Spring	JBA Mean	Lyon Mean	Lyon Median	Lyon Min	Lyon Max
Dissolved Calcium	108.5	133.7	124.6	100	125.2	133.2	138.3		123.4	87.8	84.5	19.08	181.22
	113	91.8	126.2	104.3	133.4	138.4	136.6	168.9	129.8				
Dissolved Magnesium #	10.3	15.4	6.3	17.6	8.7	12.3	14.7		12.2	10.11	8.15	0.22	30.56
	11.1	7.5	6	14.9	6.7	11.7	13.7	9.6	10.35				
Dissolved Potassium #	3.6	1.9	0.9	1.5	3.2	1.5	1.3		2.0	1.75	0.91	0.14	10.4
	3.3	1.4	0.9	1	0.9	1.4	1.1	1.1	1.1				
Dissolved Sodium #	26.5	15.1	12.8	13.7	14.8	16.7	15.3		16.4	15.52	8.97	5.1	82.31
	26.7	13.5	12.3	10.9	12	15.9	14.2	14.7	13.85				
Sulphate as SO4 #	22.1	34	36.3	29.2	38.7	62.7	40.6		37.7	14.27	8.28	0.06	96.25
	23.4	29.3	32.8	22.7	46.4	59.2	39.5	104.3	36.15				
Chloride #	50.5	23.5	25.6	17.1	21.8	28.3	15.4		26.0	24.16	14.61	6.98	131.89
	23.4	29.3	32.8	22.7	46.4	59.2	39.5	104.3	36.15				
Nitrate as N #	5.39	2.55	1.62	0.37	0.65	0.94	1.35		1.8	5.09	1.56	<0.07	44.05
	5.26	2.72	1.31	0.8	0.97	0.6	1.45	1.54	1.38				
Total Alkalinity as CaCO3	420	258	328	317	361	455	391		361.4	293.7	292.8	109.1	609.2
	600	335	333	330	624	431	414	353	383.5				
pH	7.62	7.43	7.36	7.47	7.51	7.54	7.5		7.5	7.88	7.97	7	8.47
	7.37	7.61	7.36	7.78	7.37	7.36	7.5	7.63	7.435				

Note
1) Two results are presents for each location on site. The upper is from the 17/04/2019 monitoring round and the lower is from the 14/04/2019.
2) No sample was taken from the spring in the first round.

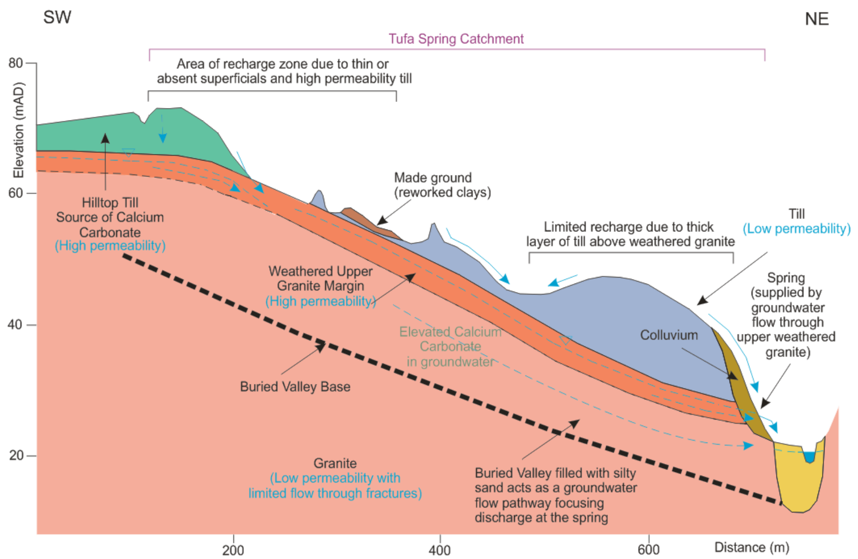
4 Updated Hydrogeological Conceptual Model

The current hydrogeological conceptual model of the tufa spring has been developed from two reports previously produced by JBA Consulting and the additional site investigation data summarised in the section above. It has the following features:

- The tufa springs form and discharge where a buried valley filled with silty sand intersects with the valley side.
- The upper weathered margin of the granite bedrock which is observed in previous site investigations acts as a relatively high permeability layer which discharges groundwater to the buried valley from the surrounding area.
- The recharge is likely to be derived from an area of thinner/absent till which overlies the bedrock and higher permeability till deposits in the upper catchment. These high permeability tills are also likely to also be a key source of calcium carbonate for the spring.
- Recharge in the area immediately uphill of the spring is limited by a thick layer of low permeability till.

The updated conceptual site model is shown in Figure 4-1.

Figure 4-1: Conceptual Model



4.1 Potential Impact Mechanisms

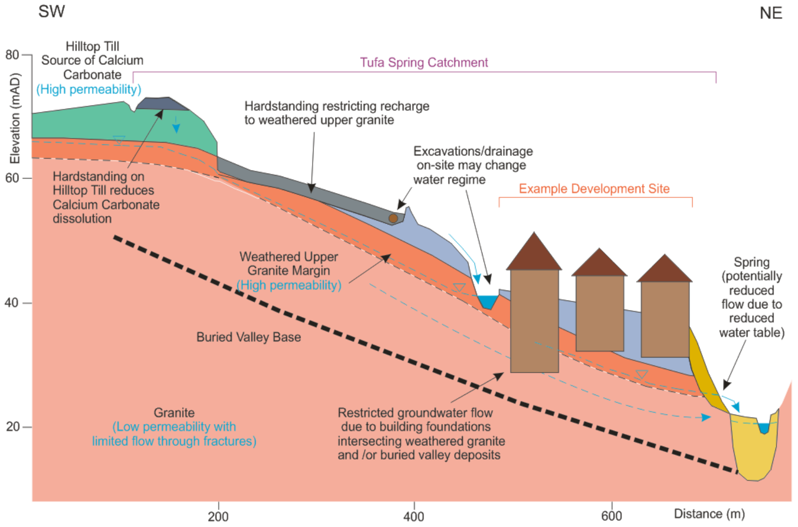
The potential impact mechanisms caused by future development can be divided into three broad categories (see table below). These are based on three key elements of the groundwater conceptual model which explains the functioning of the tufa spring.

Table 4-1: Potential Impact Mechanisms

Tufa Spring Support Element	Impact Mechanism
The water recharge zone	Reducing the permeability of the ground e.g. through construction of hardstanding over recharge area. Installation of drainage systems which divert surface water and alter the spring catchment.
Flow of water through the relatively high permeability tills, buried valley deposits and weathered upper margin of the granite bedrock.	Physical barriers to impede or divert groundwater flow (e.g. contiguous piling, foundations etc.) . Excavation below the local water table leading to a change inflow patterns, or installation of services below the water table which act as conduits for groundwater flow.
Direct Damage	Direct physical damage could occur to the tufa formation. This could lead to a change in the flow across the tufa, and the distribution of habitats on the formation.

These impact mechanisms are shown in the impact conceptual model in Figure 4-2.

Figure 4-2: Impact Conceptual Model



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5 Catchment Baseline Analysis

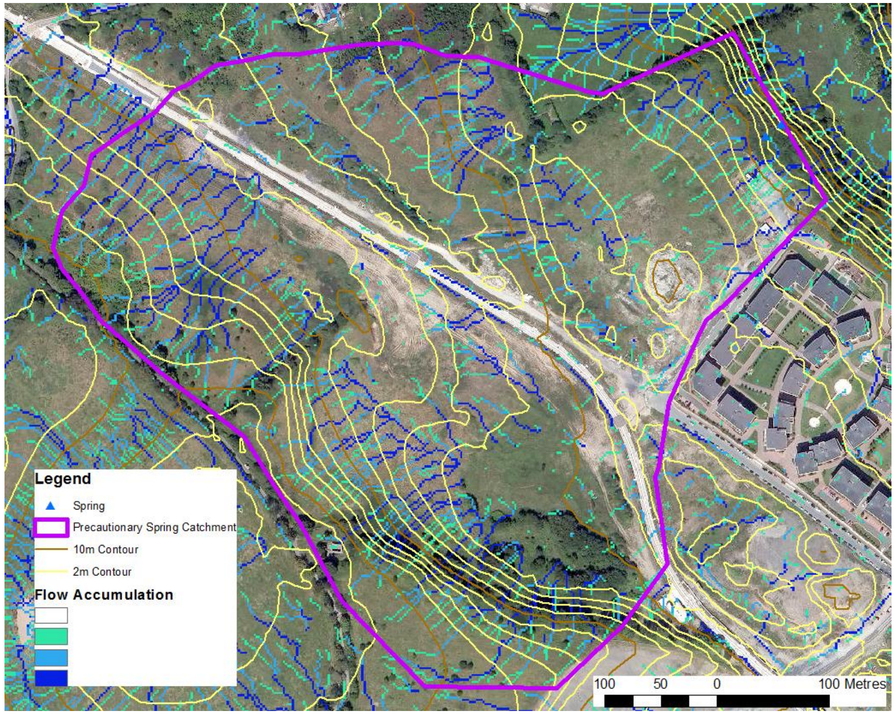
This section outlines several key elements of the analysis undertaken on the tufa catchment to identify areas which may potentially be sensitive to future development.

5.1 Precautionary Catchment Area

A Precautionary Catchment Area is shown in Figure 5-1. It is likely to be slightly larger than the true spring groundwater catchment and its extent has been defined based on the following:

- ArcGIS flow accumulation analysis to identify watersheds and main overland flow paths.
- Recharge calculations (in SBEC 2016), which suggest the catchment should be circa 28ha to account for the flow at the spring.
- The catchment excludes the existing development immediately to the south, which appears not to have affected the spring.

Figure 5-1: Precautionary Catchment Area



5.2 Intrusive Investigation Review

Data from six intrusive site investigation reports (see Table 2-1) were available for review. Appendix A presents a summary of the exploratory locations, identifying the nature and thickness of the superficial and bedrock geology. Two summary figures are presented below showing the estimated base of the superficial soils and depth to granite bedrock. Figure 5-2 shows a general slope to the top of the granite in line within general topography from west to east. The contours show the line of the buried valley west of the Luas Line and near the spring. Between those area, the site investigation locations have not identified the buried valley.

Figure 5-2: Base of Till/ Top of Granite mAD

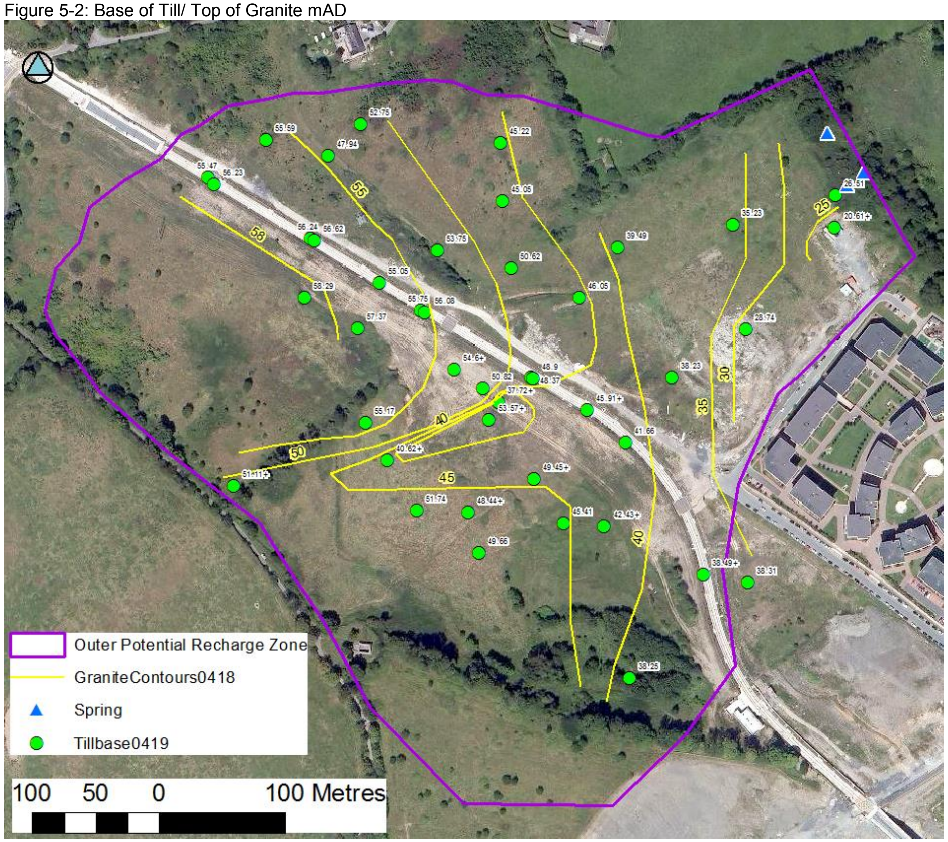


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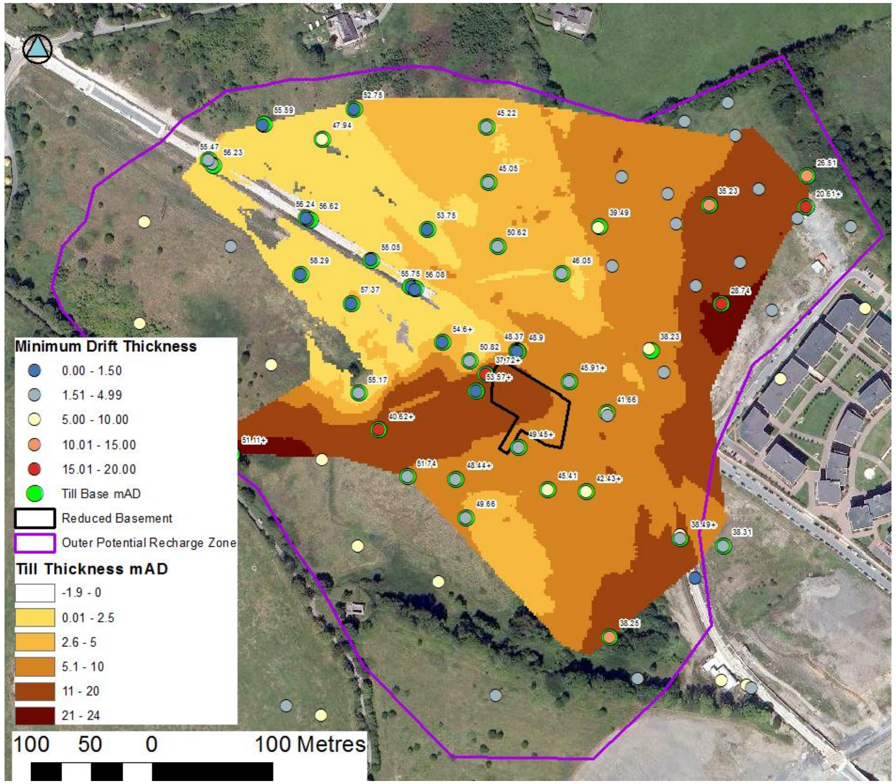
Figure 5-3: Depth to Weathered Bedrock



5.3 General Geological Classification

A review of available SI data (including that recently collected in 2018/2019), published geological mapping and topography data has been used to produce a broad classification of the geology of the catchment. This is shown in Figure 5-4 and a stratigraphic cross section is shown in Figure 5-5. There are the following classes:

- Alluvium – occupying the valley floor below the spring,
- Colluvium – till material that has migrated down the steep hill through gravity,
- Thick Till – an area of thick till (up to 17m thick) which forms a plateau above the tufa spring,
- Moderate Till – an area of moderately (approximately 2.5-5m) thick till which represents a wedging

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out of the thick till in the central area of the conjectured spring catchment area,

- Thin/absent Till – above the thick till plateau as the surrounding ground slopes upwards in the west of the catchment area. The overlying till wedges out on this slope so the bedrock lies close to the surface..This is classified as till less that circa 2.5m thick
- Hilltop Till – at the top of the catchment in the west is a plateau area underlain with till with a relatively high sand and gravel content.
- The approximate line of the buried valley identified during the most recent investigations is indicated with by dashed lines. This buried valley is filled with silty and sand rich deposits.

The entire area is underlain by granite bedrock with a weathered upper surface.

Figure 5-4: Broad Geological Classification Zones

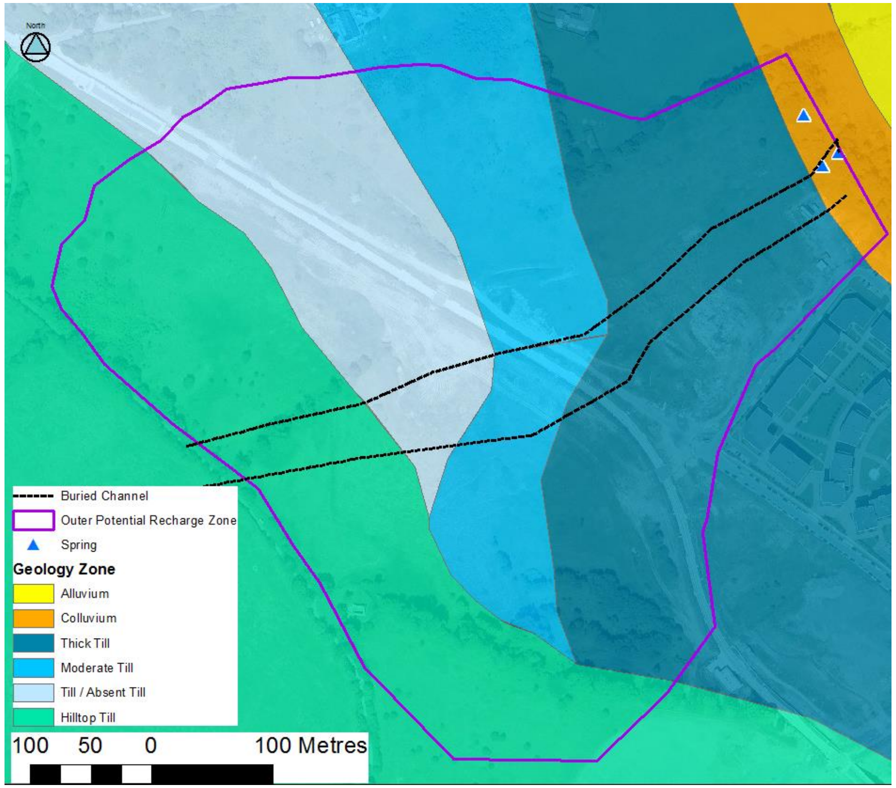
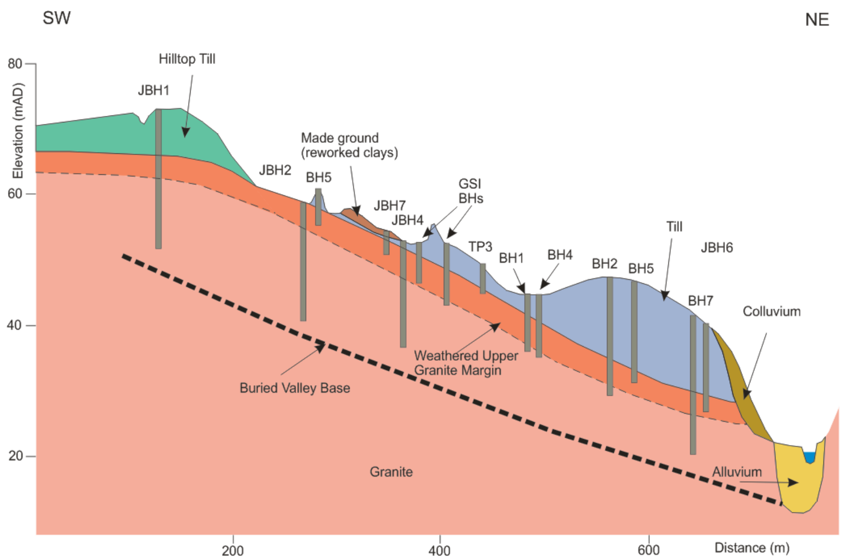


Figure 5-5: Stratigraphic Cross Section



5.4 Identifying Reworked Ground

An analysis of the SI information, LIDAR, Historic Mapping and Aerial photographs have been used to identify areas of reworked, or made ground. This includes areas of cutting and stockpiling. They are shown in Figure 5-6 and described in Table 5-1.

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Figure 5-6: Reworked Ground

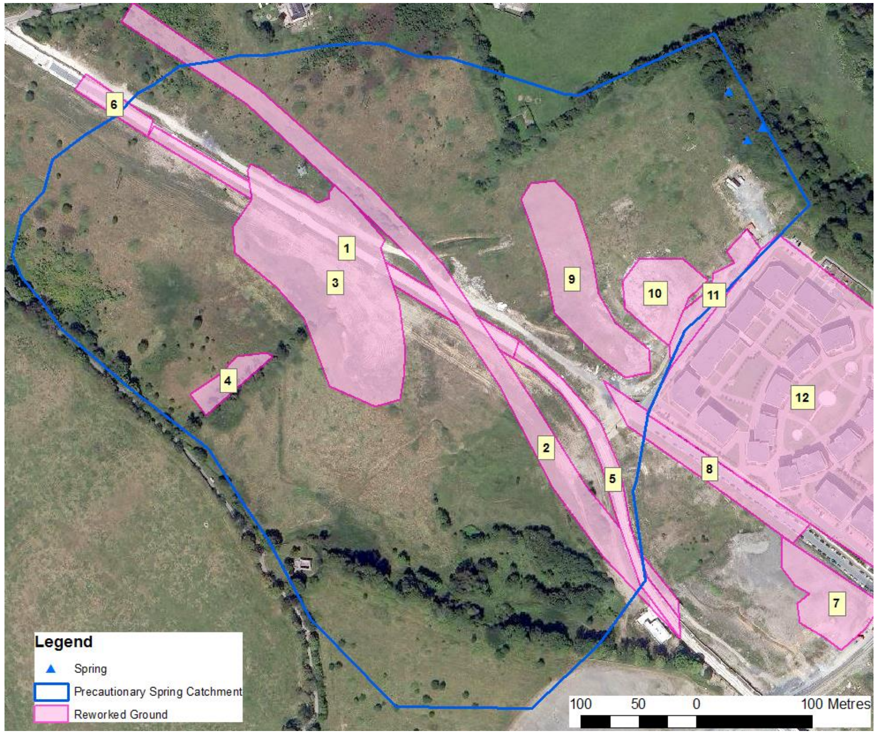


Table 5-1: Reworked Ground Descriptions

Number	Description
1	Railway line – cut section
2	Historic line of railway line
3	Area of earth stockpile (Domville SI, LIDAR and aerial photographs)
4	Historic gravel pit – 1837-42 map
5	Railway line – raised section
6	Railway line – limited cut
7	Earth stockpile
8	Road

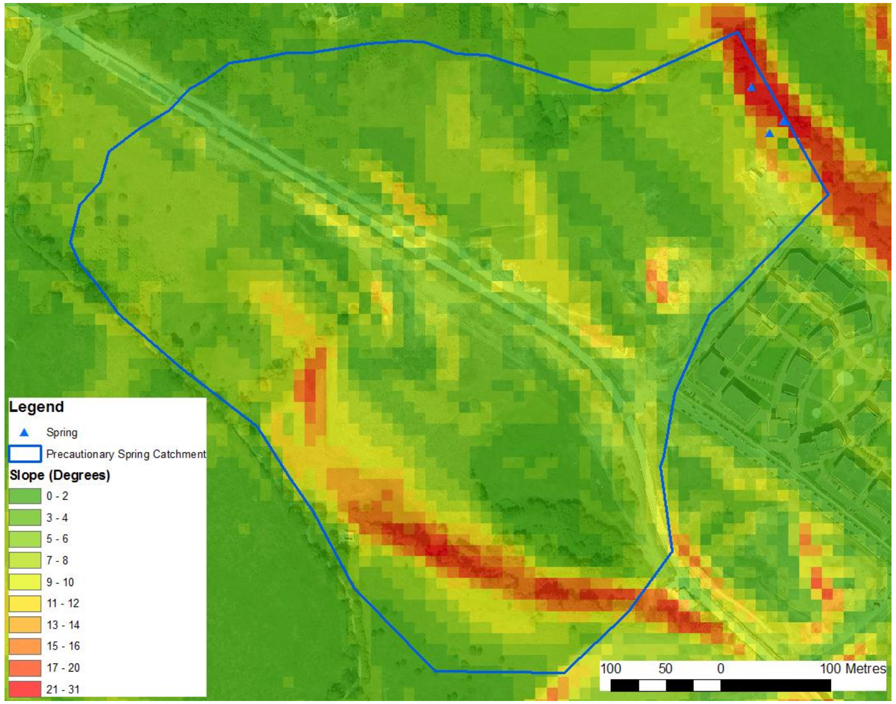
9	Thin area of made ground (SI)
10	Earth Stockpile (LIDAR and aerial photograph)
11	Section cut and levelled (LIDAR)
12	Flats

5.5 Slope and Topography Analysis

Figure 5-7 presents an analysis of slope angle across the catchment using ArcGIS analysis (of 10m aggregated version of the LIDAR data to remove “noise” of microtopographical features). It shows the following:

- The floodplain below the springs,
- The steep slope on which the springs lie,
- The plateau above the spring,
- The gentle slope further up the hill,
- The steep slope at the top of the catchment in the south, and,
- The hill top plateau.

Figure 5-7: Slope Analysis



6 Catchment Sensitivity Zone Classification

This section presents an updated catchment sensitivity zone classification scheme. The zones into which the catchment have previously been sub-divided are shown in Figure 6-1. Table 6-2 provides a description of the potential development related impacts that could arise within each zone, and the outline recommended mitigation actions. These are based on an assessment of the superficial geology coverage proven by site investigation and shown in Figure 5-4, the slope analysis provided in Figure 5-7 and the relative distances from the spring..

The following provides a short summary of development impact classes. However, it does not take into account large scale development works such as extensive and deep excavations (more that 2.5m deep) which could fundamentally alter the groundwater system and therefore the future status of the springs. **Such work, anywhere within the Precautionary Spring Catchment as defined above, should be supported by a hydrogeological risk assessment and an appropriate level of site investigation**. In certain zones, excavations less than 2.5m could be undertaken without further excavations, as they would occur entirely in low permeability till deposits. For each area, there are two Potential Impact Classes described in Table 6-1. Any proposed development should not significantly change the nature or area of the catchment of the spring, through divergence of surface or groundwater away from the catchment.

Table 6-1:Potential Impact Classes

Potential Impact Classes	Possible Mechanism	Spatial Locations Where Impact is Most Likely to Occur
Alteration of Recharge Characteristics	Reducing the permeability of the ground and infiltration of surface water through construction of extensive areas of hardstanding. Installation of drainage systems which change the spring catchment, or lead to reduced recharge within the catchment.	Where groundwater recharge rates are likely to be higher, i.e. areas where till is relatively thin (or absent), or of relatively high permeability.
Alteration of Groundwater Flow Paths	Physical barriers to groundwater flow (secant piled walls, deep foundations for undercroft parking etc.) could be built through the upper weathered margin or buried valley. Deep permanent excavation below the local water table, or installation of deep service conduits.	In the lower part of the spring catchment, where till is thick, this impact mechanism is only likely to only occur with deeper excavations. Where till is thin or absent or higher permeability development works could have the potential to alter flow paths. It has been assumed that groundwater flow paths in the lower catchment will not be significantly affected by excavations and physical barriers in the upper catchment, i.e. all except very large excavations in the upper catchment will not change the groundwater catchment of the spring

Table 4-1 identifies a third impact mechanism relating to changing groundwater chemistry (close to the spring. This impact mechanism is more likely to occur only in the vicinity of the springs in Zone 1.

Figure 6-1: Catchment Sensitivity Classification

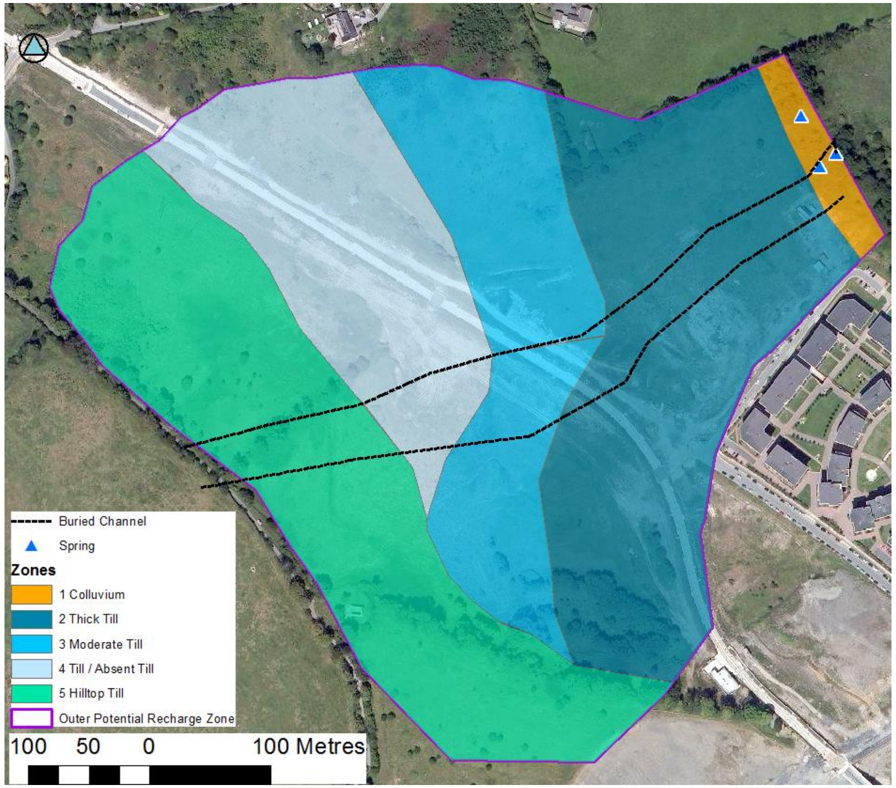


Table 6-2: Sensitivity Zone Classification

Zone	Recharge Impact Potential	Flow Impact Potential
1 - Colluvium	Zone 1 represents the slope where spring flow occurs and should be avoided in all cases	
2 – Thick Till	Unlikely – No further analysis is likely to be required.	Unlikely - No further analysis is likely to be required. Note area may be more suitable for deeper excavations further analysis would be required.

3 – Moderate Till	Unlikely – No further analysis is likely to be required	Unlikely - No further analysis is likely to be required
4 Till / Absent	Likely – Areas of proposed hardstanding and other low permeability cover will require further analysis to establish the extent of impact on recharge to the spring. Where areas can be shown to have a significant layer of low permeability till no further analysis would be required.	Likely – Excavations that are expected to reach the gravel (weathered bedrock) and bedrock layers would require further analysis to establish the extent of impact on the groundwater flow to the spring.
5 Hilltop Till	Likely – Areas of proposed hardstanding and other low permeability cover will require further analysis to establish the extent of impact on recharge to the spring.	Likely – Excavations that are expected to reach saturated deposits would require further analysis to establish the extent of impact on the groundwater flow to the spring.

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7 Domville Review

This section provides an interim summary on the proposals for basement areas below Blocks C, D and F as part of planning reference DZ17A/0714 in the light of the recent GI findings.

7.1 Updated Hydrogeological Conceptual Model

Figure 7-1 presents the location of the basement with regards to the Sensitivity Zones (from Figure 6-1) and Figure 7-2 presents a cross section through the basement. The following should be noted:

- The basement lies within the footprint of the buried valley which has been identified during the most recent round of ground investigation.
  - The GI has shown that this buried valley feature is infilled with deposits containing silty sands, which are likely to acts as a key groundwater flow path to the tufa spring,
  - The thickness of these deposits were shown to be at least 16m deep at JBH04,
  - The lateral extent of the buried valley is not well constrained, especially its southern boundary, though it appears that it is relatively steep sided.
- Recent monitoring of static groundwater levels (see Table 7-1 and Figure 7-2) indicates that groundwater levels in the north of the basement are slightly higher than the basement floor which lies at a proposed elevation of 49.37mAD. This is within the footprint of the buried valley. In the south, groundwater levels fall below the base of the basement.

Figure 7-1: Sensitivity Zones and the Basement

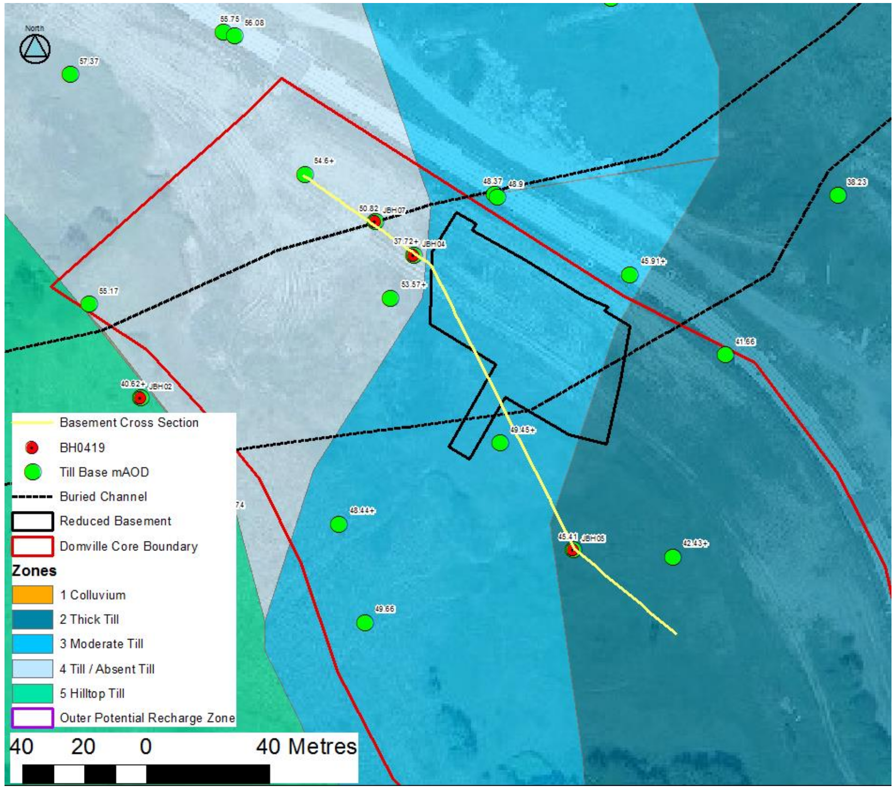

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Figure 7-2: Hydrogeological Cross Section of the Basement

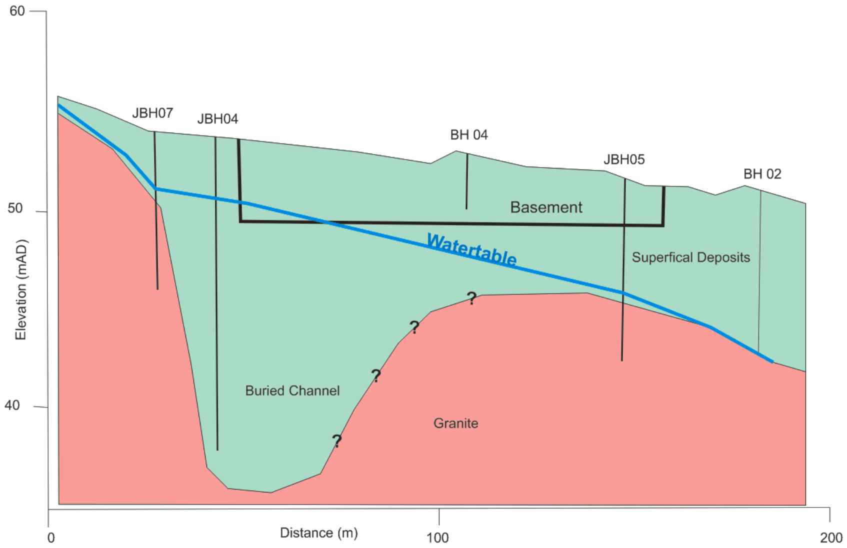

Table 7-1: Groundwater Water Level Monitoring

Sample ID	JBH - 2	JBH - 4	JBH - 5	JBH - 7
Water Level mbgl	4.2	2.98	5.75	2.44
	4.82	3.14	5.91	2.84
Water level mAD	52.22	50.74	45.16	51.58
	51.6	50.58	45	7.47

Note
1) Two results are presents for each location on site. The upper is from the 17/04/2019 monitoring round and the lower is from the 14/04/2019.

7.2 Impact Assessment Update

The table below presents the impact assessment that was competed prior to the most recent round of ground investigation (JBA July 2018) presented in Appendix A. It presents a series of potential outcomes based on what further site investigation might identify. The text highlighted in yellow are our opinion on the most likely outcomes based upon a review of existing and recent GI data.

Table 7-2: Previous Impact Assessment (JBA July 2018)

Area	Technical Conclusion
Reduced Basement during operation	The proposed new basement is all at one level – 49.37mAD. In the previous design the eastern half of the basement dropped to 45.83mAD. This reduced basement probably removes the potential for the artesian excavation impact to occur, however aquifer interaction impact is still a potential risk. There is only one borehole in the footprint of the new basement, and it shows the basement floor would be close to the top of the weather upper margin of the granite. The decision tree (Appendix B) shows the potential results of an SI, but this can be summarised as: 1. No interaction with the aquifer – no impact. 2. Interaction with the aquifer (the basement cuts into the aquifer supplying the spring) – but the aquifer is shown to be thick below the basement, so groundwater can travel underneath the basement and won't be significantly affected – no impact. 3. Interaction with the aquifer – the basement blocks groundwater flow – but water flows around the basement to the north and the south and so the supply to the spring won't change – no impact. 4. Interaction with the aquifer – the basement blocks groundwater flow and it diverts groundwater in a new direction, so the catchment of the spring is reduced – significant impact. There is only one potential outcome with a pre-mitigation significant impact, however the chance of this occurring is low, and there should be design mitigation options available (e.g. underlying the basement with a high permeability gravel layer.
Reduced Basement during construction	Construction impacts have the potential to be more significant than the long-term effects of the basement, as it could include moderate periods of dewatering activity which could reduce flows to spring. There are ways to mitigate the impact to an acceptable level which may include: - Constructing during a dry period (i.e. outside of winter/early spring) when dewatering of the groundwater body may not be required. - Constructing during extremely wet periods when flows at the spring a strong, and dewatering is unlikely to dry the spring out. - Inject pumped water back into the aquifer at a suitable downgradient location.

Groundwater monitoring data suggests that the local water table is at a similar level to the basement along its western edge. There therefore may be localised modification of groundwater flow paths around this section of the basement. However, recent GI data also indicates the presence of a deep buried valley which is likely to provide significant recharge to the spring and there is in effect a significant thickness of aquifer below the basement which will continue to provide recharge.

During construction water level monitoring indicates that part of the excavation could require dewatering. This is based on one monitoring round in April, where groundwater levels are normally expected to be somewhere nearest to their seasonal highpoint. Options to avoid possible dewatering impacts during construction are presented in Table 7-2.